18 TECHNICAL REPORT

68-23-CM

THE APPLICATION OF THE CONCEPT OF RELIABILITY TO TEXTILE PRODUCTS

by

Dr. S. J. Kennedy and Louis I. Weiner

September 1967

UNITED STATES ARMY
NATICK LABORATORIES
Natick, Massachusetts 01760

Clothing and Organic Materials Laboratory
TS-153

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S. J. Kennedy, et al

Army Natick Laboratories
Natick, Massachusetts

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AD__________

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FOREWORD

This report, "The Application of the Concept of Reliability to Textile Products," constitutes a review of the present status of reliability analysis on textile products and the possibilities for further significant studies in contributing to the objective of operational reliability. It is the further development of a paper originally presented at the 15th Annual Conference of the American Society for Quality Control on 12 February 1965, which was jointly authored by the undersigned, Mr. W.S. Cowie and Mr. A.L. Lipman.

Considered in this report are some of the problems associated with the application of "failure rate" concepts of reliability to the analysis of textile products, and "stress-strength" techniques of reliability analysis where they appear to be directly applicable to textile products.

In common with the introduction of many new sophisticated analytical techniques, the application of reliability analysis to traditional natural products such as textiles creates problems in definition and terminology which must be resolved before significant progress can be made. Some of those problems are outlined and discussed.

Acknowledgment is made to Mr. Stanley J. Werkowski of the Quality Assurance Office and in particular to Mr. Louis I. Weiner of the Clothing and Organic Materials Laboratory for whose collaboration in preparing this report I am particularly indebted.

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ABSTRACT

In common with many other natural products, the nature and use patterns of items of textile clothing and equipage are such that data for formulating exact models for predicting reliability in terms of "mission times" and "mean-times-between failures" are not easily obtainable. However, reliability analysis based upon the probability of determining whether or not a given characteristic falls within the use requirements for the material or material system has been found feasible in many cases. A considerable amount of such data is available and is presented in this report to suggest possible approaches for reliability analysis studies. Some of the inherent problems in applying reliability analysis to a broad range of textile end items are examined and discussed.

THE APPLICATION OF THE CONCEPT OF RELIABILITY TO TEXTILE PRODUCTS

Introduction

As generally used, the term "reliability" refers to the probability that an item will perform its intended function for a specified interval under stated conditions. In its current concept of use, reliability analysis embraces the prediction of reliability from early stages of item design as well as during production and through the use life of the product. Thus, a distinction must be made between reliability, as such, and use life.

Several approaches may be taken to the subject of reliability analysis. The "part failure method" is based on the assumption that product failure is a reflection of part failures. Suitable mathematical models, such as exponential functions, have been applied to permit the addition of failure rates to obtain estimates of reliability when failure rates are assumed to be constant during the useful life of the product. The so-called "stress-strength" approach to reliability involves a consideration of the "design stress" of the application and the "material strength" of the item. Although the words stress and strength have "mechanical" connotations, the principles involved in this type of analysis may be applied to other areas of performance of materials and material systems. In a sense, this method of analysis is an extension of statistical techniques of determining the probability that a given set of test data obtained in the analysis of a product will fall within specification limits which had been previously established. The validity of this technique has been pointed out by Drnas(1) as follows: "On many occasions it becomes necessary to determine an estimate of reliability of certain equipment based on data which are independent of the time-to-failure factor. In such cases reliability can be estimated by determining whether or not a critical performance parameter will fall within required specification limits."

It is suggested in this report that a useful beginning for reliability engineering of textile products lies in the application of "stress-strength" models to the significant amounts of performance and requirements data (in terms of specification requirements) which are available. With this as a beginning, consideration may then be given to time-to-failure factors as a future objective.

1. Characteristic End Points in Textiles

In a typical failure rate curve, the fai. e rate is initially shown to be decreasing with time. This characteristic decrease is attributed to corrections of defects detected as a result of quality control. The item then enters the useful or serviceable life phase during which time the failure rate is generally assumed to be constant. The product eventually reaches the end of its useful life or enters the wear-out stage. The latter period is characterized by progressively higher failure rates with increased maintenance and replacement costs. These three distinct phases in the life cycle of an item define the typical "bath-tub" shaped failure rate curve (Figure 1).

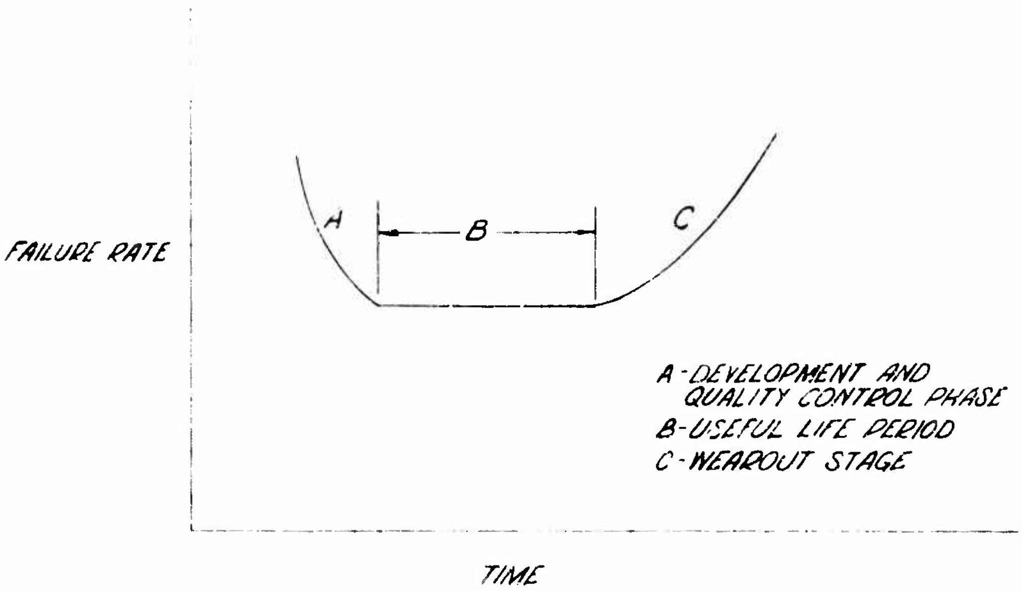


Figure 1 - Generalized "Bath-Tub" Curve

In many textile products, such as body armor, parachutes and rope, "failure" is a definite entity which may be analyzed in terms of failure rate and used to calculate reliability parameters. In other textile products, such as clothing and some types of equipment, "failure" is more difficult to determine objectively, and arbitrary criteria must be adopted if failure rate data are to be obtained. Thus, for example, a decision must be made as to the hole size or tear length or combination of the two which constitute failure.

The testing of developmental textile items is normally concerned with achieving a "balanced" serviceability of all components. Since an item, as finally developed, can be assumed to have had weaknesses of particular components and structural features corrected, a typical textile product can therefore be considered as having a low, but not necessarily a constant failure rate. Failure modes of a textile item may be associated with both a gradual wear during the useful life and also chance stress occurrences. Thus, a changing rather than a constant failure rate may be characteristic of textile items. The failure modes of textile products and problems of establishing these modes under simulated use conditions are areas that are developed and discussed in subsequent parts of this report.

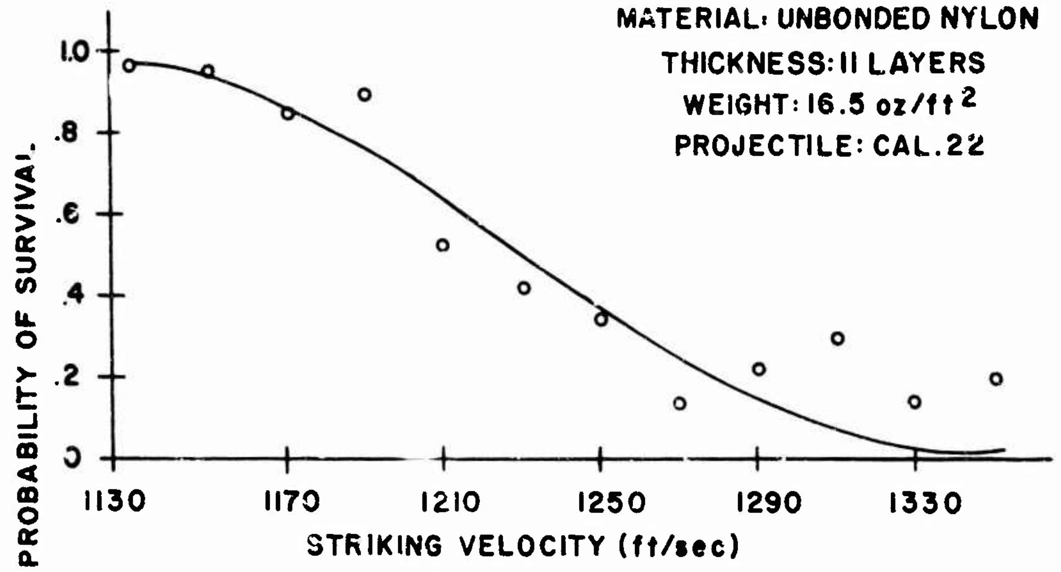
2. Testing of Body Armor

The ballistic resistance of body armor provides an example of the application of the "stress-strength" approach to reliability analysis. It is not feasible to use the time-to-failure system of analysis here, since armor either succeeds or fails at the first firing of a missile against it. However, as pointed out below, the probability of body armor effectively defeating a missile for any level of striking velocity may be predicted from appropriate "reliability" plots.

The body armor vest which has been standard for the U. S. Army consists of a composite of 12 layers of 14½-ounce, tightly woven nylon duck. Performance is measured by firing a projectile against this fabric assembly under carefully standardized conditions. The probabilities of non-penetration by a missile striking the vest have been established and form the basic criterion for rating satisfactory performance.

The test consists of firing a 17-grain, blunt-nosed cylinder of hardened steel, having a caliber of .22 inch, as a simulant of a shell fragment or a fragment of a grenade, against the composite fabric assembly. The criterion of performance is the lowest (limiting) velocity at which complete penetration of the fabric test panel (emergence of the projectile) will barely occur. Because of nonuniformity and inherent variability in the test procedure, absolute reproducible values for this limiting velocity may not be found. Instead, a probability value, called the V-50 ballistic limit, is obtained. This V-50 ballistic limit may be interpreted as the striking velocity at which 50% of the individual impacts will result in complete penetration.

Typical curves plotted from data obtained by firing hundreds of rounds of fragment simulators at different velocities are shown in Figures 2 and 3.

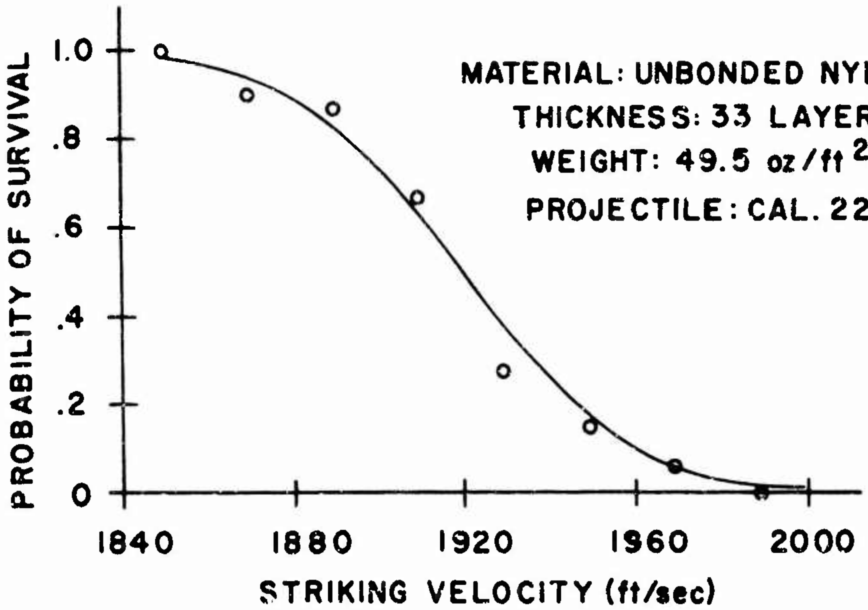


PROBABILITY OF SURVIVAL (NON-PENETRATION) VERSUS STRIKING VELOCITY

Figure 2

In Figure 2, test firing data are shown for a fabric assembly of 11 layers of nylon ballistic fabric with the striking velocity ranging from approximately 1100 to 1300 ft/sec. For this number of layers of fabric, we can obtain a nominal 100% probability of defeating the missile at the lower velocity range, and 0% probability of defeating the missile at the upper velocity range.

As the number of layers and, consequently, the weight of nylon fabric is increased, as shown in Figure 3, the probability of non-penetration of the fragment simulators shifts to higher velocity levels.



PROBABILITY OF SURVIVAL (NON-PENETRATION) VERSUS STRIKING VELOCITY

Figure 3

With 33 layers of fabric, the experimental data correspond quite closely to the smooth curve drawn among the plotted points. For these heavier weight fabric assemblies, the velocity range over which the probability of non-penetration drops from 100% to 0% is somewhat narrower than for the lighter weight assemblies.

Here the probability of satisfactory performance is related not to continuous or repetitive use but to a particular level of performance against a one-time use, and to striking velocity of the test projectile rather than time as the independent variable. Furthermore, reliability is dependent directly upon the required level of performance which must be based on the limits of production capability determined by the current state of the art. For a given level of ballistic resistance, therefore, reliability may vary over a considerable range. Such variation is consistent with the basic definition of reliability which considers the probability of an item performing its intended function under "stated conditions."

3. Reliability in Parachutes

In addition to instances described, there are also a limited number of textile uses where reliability in its usual meaning applies. In these cases, failure may occur as a result of repeated loading of the tested material in extension, as in ropes, or by the rupturing of a diaphragm made of a textile material.

Uses of this type, however, are for the most part, not subject to usual reliability analysis because of conventions regarding textiles for which they had been developed. Where possible failure might occur in such a use, it has become conventional to engineer the product so that the reliability level can be held close to 100%. Thus, a sufficient margin of safety is designed into the product so that at the time maximum stress occurs, an absolutely minimal number of failures can be anticipated.

In parachutes there is a relatively complex assembly of different textile materials and metal hardware. On personnel and certain other types of parachutes, reliability of material components must be based on a knowledge of the stresses of opening shock. For extraction parachutes used in drawing heavy loads, such as artillery and vehicles, out of a plane, another concentration of stress may occur after opening.

Laboratory testing of parachute components must be conducted at the same rate of application of stress that occurs in the normal use of the item in the field. As shown in Figure 4, only a portion of the possible application ranges is covered by existing high-speed testing equipment. Development of

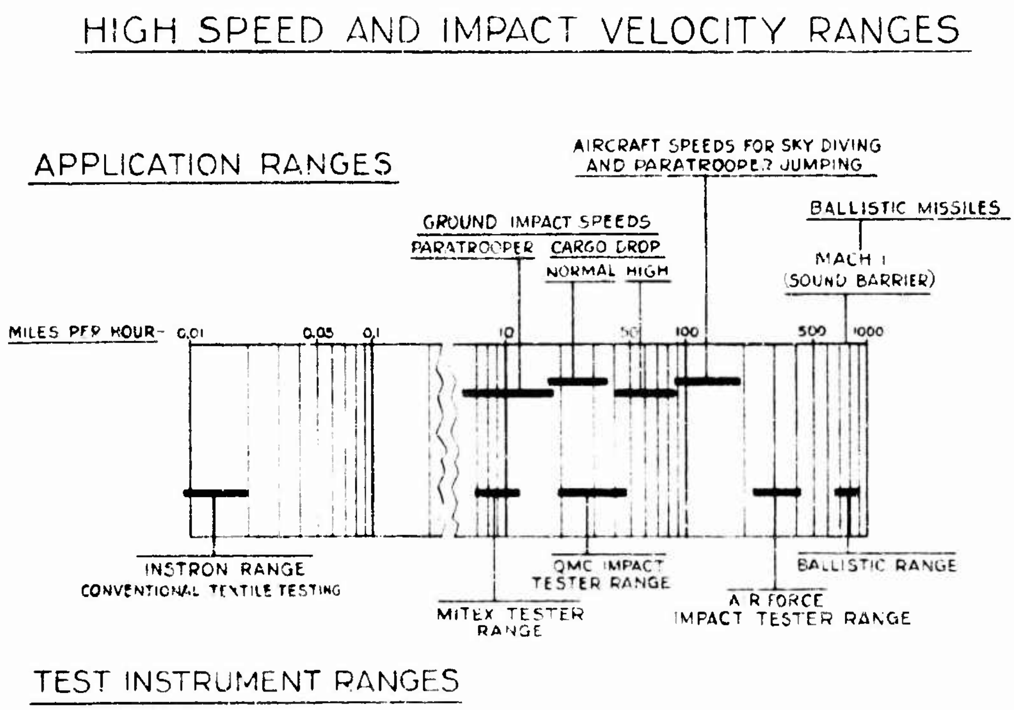


Figure 4

supplementary equipment to cover the sub-ballistic range for some parachute applications appears desirable. The principle that is followed for personnel, cargo, and extraction parachutes is to maximize reliability of all components that might cause malfunction, with the objective of approaching 100% reliability in the system. The design and construction of the parachute is such that material failures rarely, if ever, become the source of malfunction. Detailed analysis of malfunctioned parachutes conducted over a period of close to a decade has failed to reveal any case where the malfunction could be attributed to material failure. In instances where material damage was observed in malfunctioned parachutes it was noted to have been a result of the original malfunction and not the cause of it. In considering the classic bathtub-shaped curve of failure rate versus time, it is interesting to observe that parachutes are one class of textile product in which failure rate is close to zero over long periods of time. There are many instances where parachutes perform in a completely satisfactory manner after having had 100 previous jump experiences.

Parachutes also typify a problem in reliability which arises from the possibility of deterioration of a textile material in use or storage, due to age and the influence of heat and light. Without a fully reliable means of nondestructive testing of individual units and components, there may always be a question of the degree of reliability of old stocks. Therefore, the original reliability estimate used in engineering the product will not be sufficient to insure reliability after use unless precautionary care is taken to avoid conditions which may lead to loss of strength during use and storage, for example, avoidance of unnecessary exposure of the canopy to ultraviolet light.

4. Reliability in Thread

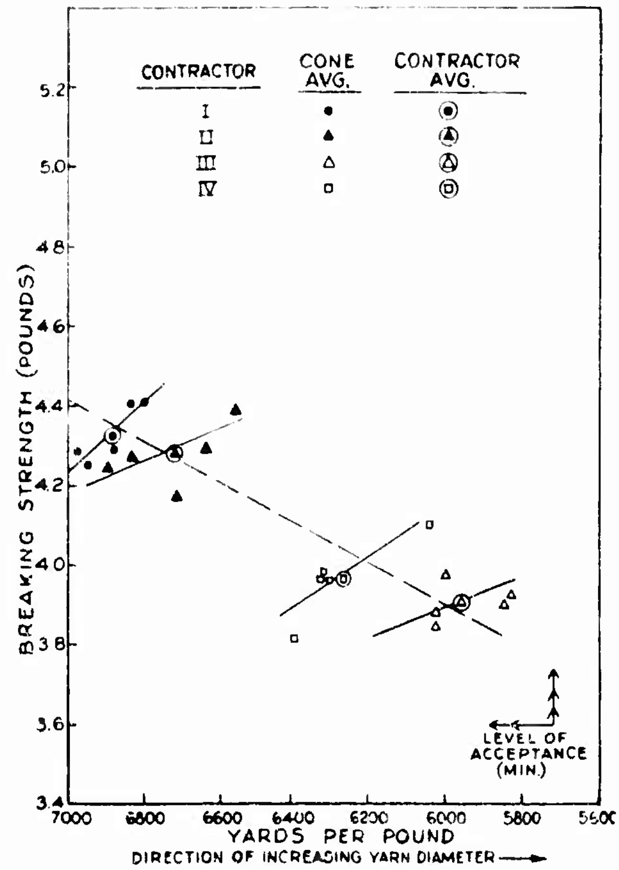
Sewing thread presents a similar problem, although here the critical problem from the standpoint of the thread manufacturer and the purchaser of industrial threads, such as garment manufacturers, is the reliability of sewing thread as measured in terms of the probability of successful sewing without thread breakage. Because of the low cost of thread in relation to the labor cost involved in machine stoppage and rethreading, it is obviously cheaper to use a thread that is stronger than actually required for a seam. Also, it is economical to lubricate it properly, if in so doing the avoidance of thread breakage can be assured and reliability maximized.

The critical nature of this problem will be immediately evident if one considers the fantastic stresses placed upon sewing threads, which may be subject to velocities of as much as 60 meters per second in high-speed sewing machines operating at 5000 stitches per minute. Accordingly, the sewing thread manufacturer seeks to optimize the sewing properties of his threads by the use of low-friction finishes or by selection of raw materials so that his product will sew at anticipated speeds and other use conditions without breakage. If the user does experience excessive breakage, he can step up to the next heavier thread and solve his problem that way or change to the thread produced by another manufacturer who produces a higher quality item. The reliability, in any event, is estimated simply by "sewability", i.e., the ability of the thread to sew without breakage. High levels of reliability can be assured simply by selection of the proper size and strength of thread.

Figure 5 shows the variations that may exist in breaking strength of thread of the same nominal size, as produced by different manufacturers. The breaking strength values obtained are all above the minimum level of acceptance as shown by the indicator of specification requirements in the lower right-hand corner. However, among contractors, as the size of their thread increases (decrease in yards per pound) based primarily upon the grade of cotton used, the breaking strength <u>decreases</u>, while within a given contractor's production as the size of the thread increases, the breaking strength <u>increases</u>. This is one of the complexities of stress translation in textile structures which often makes conventional reliability analysis difficult to apply.

The garment manufacturer encounters difficulty in the application of reliability parameters in the conventional sense because of the problem of defining accurately the exact conditions of use of the thread. From one operator to another, or from one machine to another, or from one material to another, the reliability of the same thread in sewing can vary a great deal. Operator training and machine adjustments are the simplest means for making the thread sew properly, which is all the garment fabricator is concerned with.

This statement on thread illustrates another aspect of textiles which limits the extent to which reliability indices can be made significant; namely, that reliability in textiles during their service life is a function of the way the consumer uses a textile item and the kind of wear he gives it. This may be much more applicable to textiles than to some other kinds of items, i.e., the environment or conditions of use of a textile material will rarely be the same from one consumer to another.



RELATION OF THREAD SIZE
TO BREAKING STRENGTH
(24/3 THREAD)

Figure 5

5. <u>Reliability of Rope</u>

Variability of conditions of use is also an important factor with many non-apparel items. A good subject is mountain-climbing rope, a textile item which has a go-no-go characteristic but where performance is related in only a very limited way to time in the sense of repetitive use.

As with parachutes, we have a "life-and limb" item, but here instead of engineering to meet every possible contingency, the item is characteristically engineered to permit weight-saving because, if properly used, the rope will never be subjected to maximum potential stress.

The specification requirement for the Military Standard 7/16-inch mountain-climbing rope calls for a breaking strength of 3000 pounds, when tested on conventional laboratory equipment at a loading rate of 12 inches per minute.

However, as has been pointed out by Wexler[2], this rope will fail if a man weighing only 132 pounds falls for a distance of only twice the length to which he is attached; for example, a 10-foot fall on a 5-foot length of rope, if he falls from a static belay in a perpendicular drop (a strength loss of 50% is allowed for the knot).

This aspect of rope performance has become so critical that the International Union of the Association of Mountain Climbers (UIAA), a major climbing organization of 10 European countries and the United States, has standardized[3] on a rope impact test which involves a free fall of a weight over a distance of 14 feet, utilizing a carabiner in series with the rope as shown diagramatically in Figure 6.

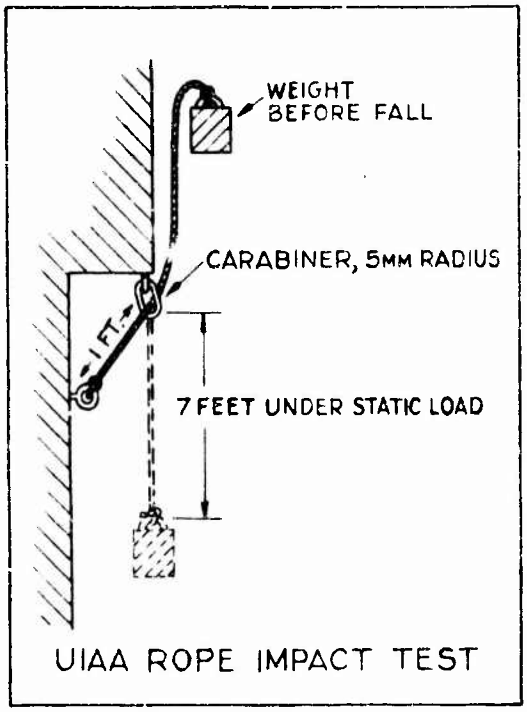


Figure 6

Actually, experienced mountain climbers will accept a rope having a reliability factor far less than they would theoretically require, not because they are unaware of the danger of the rope failing to meet the full reliability requirement but because they anticipate being able to use either a resilient belay in which energy is absorbed by the rope moving across their body, or a dynamic belay in which the rope is permitted, under control, to slide over the support, with the friction generated between the rope and support used as a means of absorbing the energy of the fall. Both of these types of belays require skill in their use. However, through knowledge of how to make such belays, minimum reliability of rope strength can be accepted. It is evident from this instance that the conditions of this use make the computation of a reliability factor difficult, since they are subject to determination only at the exact moment and in the particular environment when and where the fall occurs.

In a study[4] in which 20 mountain-climbing ropes were carefully analyzed after use, the strength of the ropes in many cases had deteriorated as much as 50% due to surface friction at the time when they were turned over to these laboratories for analysis. However, there was not a single instance where a fatal accident had occurred due to the failure of any of these ropes during use. In addition, analysis of 10 years' records of mountain-climbing accidents compiled by the Safety Committee of the American Alpine Club fails to reveal evidence of an accident caused by rope failure.

6. <u>Typical Textile Serviceability End Points</u>

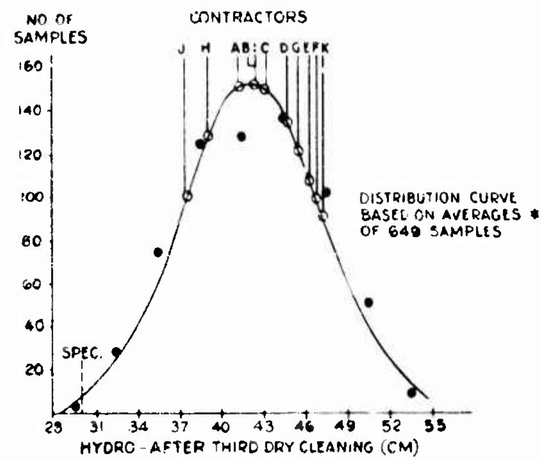
As pointed out previously, the reliability of textile products may vary in terms of failure rate during the normal use life of the product. However, in so many textile products "failure" is determined subjectively by the user, based upon characteristics which may be totally unrelated to the projections of the designer and thus make the objective assignment of reliability parameters meaningless.

Thus, the typical end of a useful service life for most types of textile products for one individual is totally different from that for another person, and their different appraisals as to whether the item is still useable; for example, whether it has

been worn to the point of being shabby or damaged so that it can no longer be worn in public, whether they feel it is out of style and they can afford to replace it with something more in keeping with their social status, and whether it is outgrown. One consumer may mend a garment while another throws away one just like it; or one person may consider a garment as no longer presenting an acceptable appearance, while another would consider it wholly satisfactory and wear it far beyond the point at which the first person would have discarded it. Thus, the end of service life of most textile products is a subjective determination, and as such is not capable of objective prediction.

Furthermore, an essential characteristic of serviceability of textiles is the continuum of their performance, with gradual loss of satisfactory performance, rather than an abrupt termination of serviceability. In contrast, for mechanical and electronic equipment, mathematical models have been developed and used with a relatively high degree of success. These models define failure in terms of "cycles to failure," "hours to failure," or similar expressions. For example, a light bulb functions with complete satisfaction until the filament burns out; then the bulb has absolutely no usefulness. These models have one thing in common; they define failure at a given "point" estimate.

What has been done in recent years[1] to obtain the reliability of such products whose use patterns cannot be readily translated into time-to-failure factors is to estimate reliability from the probability that a given performance property will fall within specification limits. A number of years ago,[5] several of the critical specification requirements for textile materials, such as breaking strength, tearing strength, shrinkage and water resistance, were examined in terms of the distribution of test data obtained from randomly selected samples of a population. The values obtained were normally distributed and formed the basis for estimating the probability of the specification requirement being met. A typical distribution of this type for the "hydrostatic resistance" of a wind and water-resistant sateen (used in the outer layer of cold weather combat clothing) is shown in Figure 7. Using the techniques recommended by Drnas[1], such data may be used to obtain estimates of reliability.



*THREE MEASUREMENTS OR TEST MADE ON EACH SAMPLE AND THE AVERAGE OF THESE THREE RECORDED AS A REPRESENTATIVE VALUE FOR THE SAMPLE.

Figure 7

7. The Measurement of Service Life - Wear

What has been sought for in this field by many competent technologists over many years, and particularly by the U.S. Army Quartermaster Research and Development Command, now the U.S. Army Natick Laboratories, has been the means for measuring service life in terms that might be related to actual wear. During World War II, the development of garment wear courses at Ft. Lee, Virginia, as a means for evaluating the relative durability of different materials, and the durability of assembled textile items of clothing and equipment, their component materials and their joining seams, opened the way for studies of a type and breadth which had heretofore never been attempted.

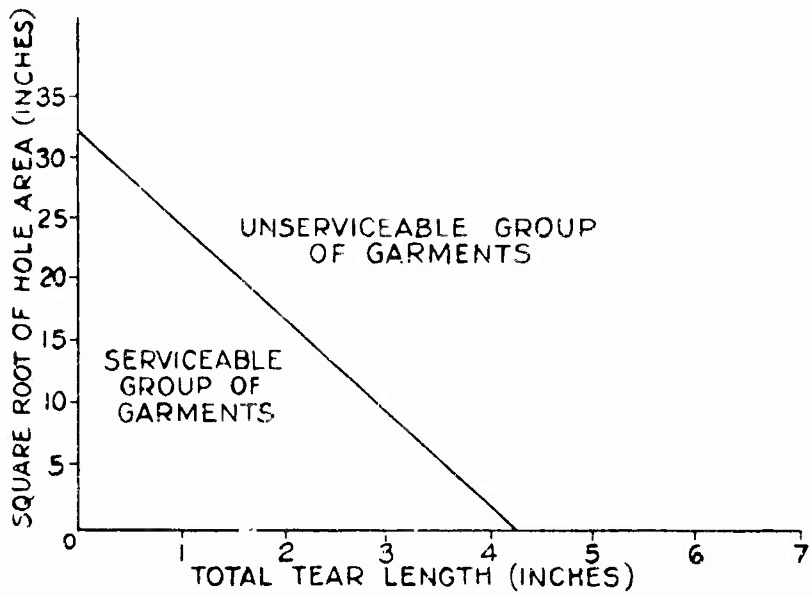
Also, during World War II, our organization began a thorough study of what might be termed end point characteristics of textile products, based upon the analysis of the kinds and degrees of failure of items which had been discarded and classified for salvage. Recently, the techniques which we have used for analysis of textile products in these "salvage studies" were written up in a summary statement in a report entitled, "Techniques for Salvage Analysis of Clothing, Footwear and Textile Equipage," Textile Series Report No. 126 (6) dated July 1963.

These studies had a different purpose than that of establishing reliability factors. Their purpose was the correction of points of weaknesses in these items to obtain a more balanced service life, and to reach toward the ultimate of the one-horse-shay: "The Deacon's Masterpiece," (7) However, these studies have thrown significant light upon the phenomenon of the end point in the serviceability of textiles.

In a large population, such as our military forces, where standardized items of clothing and equipment are used, it might be expected that an identification of the end point of serviceability might be found. To a limited degree this has been true. However, because of the wide variability in the degree of damage of garments turned in for salvage, average end points cannot be described. Instead, a more useful and more realistic approach to the problem has been the development of a scoring system for rating the degree of damage found in such items. With such a system, failures in discarded garments can be evaluated and a statistical measure of the degree of failure can be determined for use in serviceability analysis.

Several scoring systems have been devised to measure the degree of wear observed on garments. At the Field Evaluation Agency, Ft. Lee, Virginia, the four types of wear (holes, tears, frays, and wear areas) have each been given an arbitrary number, designated as "degree of failure." The length of tears and frays and the diameters of holes are measured in inches; the areas of wear are measured in square inches. To increasing class intervals for each type of failure, a degree from 1 to 6 inclusive is assigned. Point values for each degree and type of failure are arbitrarily assigned. The sum of the point values for a particular garment constitutes its "wear score" over a given time period (traversals of the wear course) and, therefore, a measure of how long it wore.

The problem of assigning a meaningful weighting to the various categories of wear has been investigated by Greenland and Reid.(8) They used the technique of discriminant analysis, in which the judgment of skilled observers as to the serviceability or lack of serviceability of a series of garments is compared to an objective scoring based upon such parameters as hole area and length of tears. Figure 8 is a reproduction of a plot from Greenland and Reid's paper in which the square root of hole area is plotted against total tear length for a group of garments which had been rated as unserviceable or serviceable by an expert classifier.



DISCRIMINANT ANALYSIS TECHNIQUE FOR ESTABLISHING
A REALISTIC WEAR SCORE SYSTEM

Figure 8

The straight line drawn down across the plot represents the line that best discriminated between these two groups of garments. The area above and to the right of the line contains the data for those garments which were rated unserviceable (i.e. - high values of tear length and hole area), and the area below and to the left of the line contains the data for those garments which were rated serviceable (i.e. - low values of tear length and hole area). The equation of this straight line can then be used to obtain the discriminating wear score-values greater than which would indicate that the garment was no longer serviceable and values less than which would indicate that the garment was still serviceable. For the line illustrated in Figure 8, the slope was found to be approximately 7.1 and the equation for wear score would be:

$$W.S. = \sqrt{H} + 7.1T$$

where $W.S.$ = wear score

$\sqrt{H}$ = square root of hole area

T = tear length

To relate these scores to actual periods of wear in normal use, studies have been made of the wear of the same garments on troops during basic training. For some types of fabrics, a useful correlation has been established between accelerated "wear course" wear and normal "field wear" in basic training. Figure 9 shows plots of the wear of garments made from a 50/50 blend of cotton and nylon. The upper curve represents weeks of "field wear" at Ft. Jackson versus cumulative wear score and the lower curve represents cycles of "wear course" wear at Ft. Lee. The positioning of the abscissae values with respect to wear score is such as to show the correspondence between the two types of wear for this one blended fabric. Up to about 9 cycles of "wear course" wear, the agreement between the two evaluations is quite good, and a useful estimate would be that 5 cycles of "wear course" wear is equivalent to 20 weeks of "field wear," or 1 cycle is equivalent to four weeks of "field wear." However, because of both the cost and the effort involved in conducting studies of this kind, concentrated effort has been placed upon duplicating such wear patterns by the use of laboratory test equipment.

RELATIONSHIP BETWEEN FT. LEE WEAR COURSE & FT. JACKSON FIELD WEAR
OF 50/50 COTTON/NYLON SATEEN (9.8 OZ.)

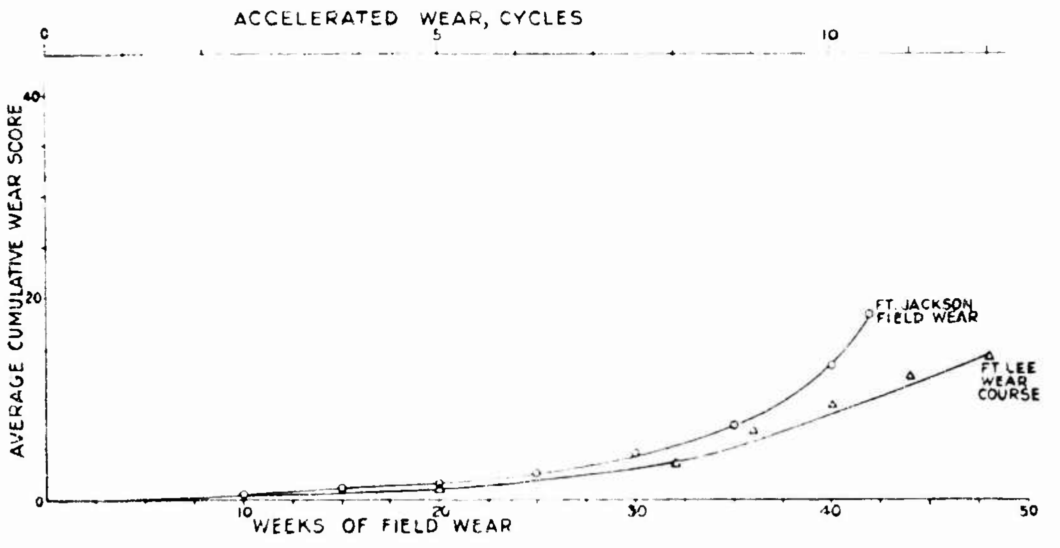


Figure 9

A major contribution was made in this direction by Dr. Reiner Stoll who developed the Stoll-Quartermaster abrasion tester for the Quartermaster Laboratories. He dealt with the identification of the end point by developing an electrical device for automatically stopping the machine when failure due to abrasion occurred. On his flex tester, the end point was reached when the fabric broke. Later, significant work in this field was done by Dr. Stanley Backer when he was on the staff of the QM Laboratories and more recently by Mr. Louis I. Weiner, and by Mr. Harry F. Smith in the development of the sand abrader (Fig. 10).

It would be gratifying if it could be said that the measures of serviceability reflected in these scoring systems, combat courses, and laboratory instruments could give us end points which could be used in predicting useful service life, and incidentally provide reliability data. Unfortunately, this is not the case. Correlation of any laboratory data satisfactorily with service use is still ahead of us. The number of variables introduced by the blending of fibers, the use of a multitude of different finishes on the fibers, or impregnated within them, to provide certain functional properties, or simply to lubricate them, make it impossible at this time to state with any certainty just what the results from any laboratory wear tester really mean in terms of actual service life.

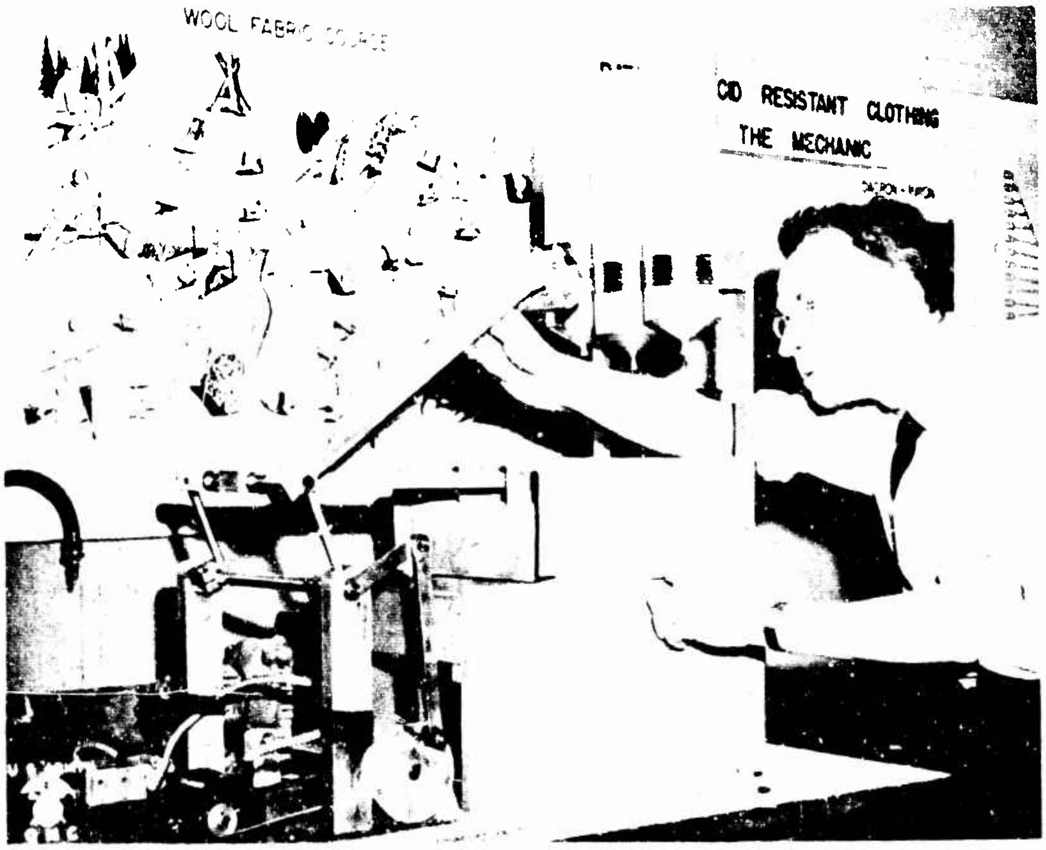


Figure 10

8. <u>Service Life Other Than Wear</u>

There are two other basic areas also involved here, beyond just serviceability in terms of wear.

One is related to other aspects of performance for which reliability data may be required. These include colorfastness to washing and to light, and the effectiveness of such functional finishes as may have been applied to the fabric, both originally and after use and laundering. In respect to these performance aspects, it must be borne in mind that there are distinct limits imposed by the state of the art and by the character of the materials. While significant progress has been made and is being made, there are requirements in respect to reliability that certainly cannot be met at this time, such as a requirement for lightweight clothing that will protect a man against a gasoline fire for more than a few seconds.

The other area pertains to the nature of textile products as assembled items. Clothing and footwear are, in this respect, like an automobile - assembled items consisting of various different materials put together by sewing or other joining operations. Therefore, when we speak of reliability of the end product, we are referring to the reliability of the total assembly. All components are expected to be of reasonable, equal serviceability, barring accidental damage for which no reasonable precautionary measures could have been taken and still meet the other requirements for the item.

9. <u>Principles of Serviceability for Textile Items</u>

This leads to the first basic principle in respect to serviceability (or reliability) of textile items: the "one-horse-shay" principle -- that the service life of all components should be comparable in the use to which they are put.

This does not mean that interlinings, for example, must be as strong or as durable as outer fabrics. It simply means that when they are used as interlinings, they will function satisfactorily as interlinings for the life of the garment. Presumably a test of the item to destruction, that is, a statistically planned test of an appropriate number of the items, might demonstrate whether a particular interlining material, among many competing materials,

was satisfactory. It would not necessarily demonstrate that the competing materials, which may have an equal claim to being used, were satisfactory. Time and cost make such testing impracticable. Accordingly, prior experience with materials of this kind, and limited evaluations made by qualified technical personnel in this particular craft field, must serve as a basis for determining if a particular component material of this type may be used.

The second basic principle with respect to performance of textile materials is that priorities must be established, or accepted based upon general practice, with respect to serviceability (or reliability) of textile products in reaction to other conflicting requirements. It is characteristic of textile materials and the uses to which they are put that the consumer wants a host of different properties which are mutually incompatible, for example, lightness in weight, and comfort as well as serviceability. In many cases if the comfort aspects are given a priority, serviceability will have to be reduced. This was recognized recently as U. S. Army policy with respect to the soldier's clothing and equipment in the adoption of the LINCLOE* program for Conserving the Energy of the Combat Infantryman. Just what balance should be struck between such differing requirements involves a complex technical judgment. This is particularly true where as many as six or eight different requirements all apply to the same clothing system, as is typical of today's combat clothing.

A third principle is that, despite the difficulty of interpreting laboratory data in terms of field serviceability, such data can be used as a general guide, although not a completely reliable guide, in making judgments as to where and how to compromise these conflicting requirements in the selection of particular materials or construction techniques or patterns. Interpretation of these data should, however, be left to qualified technical personnel who are completely familiar with the assumptions of the test methods, and the limitations of data so obtained in their application to particular items or situations.

In conclusion, it is not to be expected that, in the foreseeable future, reliability data of textiles and related materials and products made from them will become available from any source which can be subjected to rigorous reliability analysis, unless estimates of reliability made from probabilities of critical performance characteristics meeting specification requirements are accepted as valid. If quantitative data in respect to serviceability are

*Lightweight Individual Combat Clothing and Equipment

desired, programs such as those conducted at the U.S. Army Natick Laboratories and its predecessor organizations should be continued on a substantially enlarged basis over a period of several years. This should be done until at least the character of the variables involved in the use of different fibers, alone or in blends, and the effects of different finishes on the fibers and fabrics are understood. Through these programs some principles can be developed, based upon which appropriate laboratory instrumentation and techniques may be devised for making such measurements.

10. References

1. Drnas, T.M., "Methods of Estimating Reliability," American Society for Quality Control Journal, September 1966.

2. Wexler, A., "The Theory of Belaying," American Alpine Journal, 7, 379 (1950).

3. Armitage, J., "Safe Climbing Equipment: Ropes and Belays," 12, 24 (1966).

4. Weiner, L.I., "Extent and Cause of Deterioration of Nylon Mountain Climbing Rope," Textile Series Report No. 143, U.S. Army Natick Laboratories, Natick, Mass. (1966).

5. Backer, S., "The Use of Acceptance Testing Data to Substantiate Specification Requirements," Textile Series Report No. 34, U.S. Army Natick Laboratories (1947).

6. Kennedy, S.J., Johnston, J.E., Frederick, E.B., and Weiner, L.I., "Techniques for Salvage Analysis of Clothing, Footwear, and Textile Equipage," Textile Series Report No. 126, U.S. Army Natick Laboratories, Natick, Mass. (1963).

7. Holmes, Oliver Wendell, "The Deacon's Masterpiece," McGraw-Hill Book Company, New York, New York, 1965.

8. Greenland, J. and Reid, A. M., "The Present Position of the Improved Wear Score System in the U.K.," Seventh Commonwealth Defense Conference on Clothing and General Stores, London (1961).

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13. ABSTRACT

In common with many other natural products, the nature and use patterns of items of textile clothing and equipage are such that data for formulating exact models for predicting reliability in terms of "mission times" and "mean-times-between failures" are not easily obtainable. However, reliability analysis based upon the probability of determining whether or not a given characteristic falls within the use requirements for the material or material system has been found feasible in many cases. A considerable amount of such data is available and is presented in this report to suggest possible approaches for reliability analysis studies. Some of the inherent problems in applying reliability analysis to a broad range of textile end items are examined and discussed.

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Estimation	8		4			
Reliability	8,9		4			
Textiles	9		9			
Clothing	9		9			
Equipment	9		9			
Body armor	9					
Fibers	9					
Parachutes	9					
Rope	9					
Range (Extremes)	10		8,9			
Performance	10		8,9			
Parameters	10		8,9			
Quality control	4		4			
Determination			8			

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